1.1 An Investigation of the Influence of Urban Areas on Rainfall Using a Cloud-Mesoscale Model and TRMM Satellite

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1.0 Introduction

The urban heat island (UHI) has become a widely acknowledge, observed, and researched phenomena because of its broad implications. It is estimated that by the year 2025, 80% of the world's population will live in cities (UNFP, 1999). The UHI has been documented in the literature to affect local and regional temperature distributions, wind patterns and air quality. The UHI can also impact the development of clouds and precipitation in and around cities. This paper will focus primarily on the UHI's impact on precipitation.

In the past 30 years, several observational and climatological studies have theorized that the UHI can have a significant influence on mesoscale circulations and resulting precipitation (see Shepherd et al. 2002 for a thorough review). More recent studies have continued to validate and extend the findings from pre- and post-METROMEX investigations. Shepherd et al. (2002) was one of the first (and possibly the first) attempts to identify rainfall modification by urban areas using satellite-based rainfall measurements. Using a 15-month (spanning three years) analysis of mean rainfall rates, the cities of Atlanta, Montgomery, Dallas, Waco, and San Antonio were examined. *Shepherd et al. (2002) found that the average percentage increase in mean rainfall rate in a hypothesized "downwind maximum impact area" over an "upwind control area" was 28.4% with a range of 14.6 to 51%.* The typical distance of the downwind rainfall rate anomaly from the urban center was 30-60 km, consistent with earlier studies. This fact provides confidence that UHI-rainfall effects are real and detectable by TRMM satellite estimates.

A recent U.S. Weather Research Program panel concluded that more observational and modeling research is needed in the area of urban-induced rainfall anomalies (Dabberdt et al 2000). In terms of modeling research, several studies have addressed the evolution and impact of the UHI on the environment, but very few have focused on the impact to precipitation processes. Kidder (1999) provide a fairly thorough review of UHI modeling studies that do not specifically address the precipitation modification. Investigators have begun to explicitly address the impact of urban surfaces on rainfall processes (Thielen et al. 2000; Baik et al. 2001).

Herein, a convective-mesoscale model with extensive land-surface processes is employed to (a) determine if an urban heat island (UHI) thermal perturbation can induce a dynamic response to affect rainfall processes and (b) quantify the impact of the following three factors on the evolution of rainfall: (1) urban surface roughness, (2) magnitude of the UHI temperature anomaly, and (3) physical size of the UHI temperature anomaly. The experiments are achieved by inserting a slab of land with urban properties (e.g. roughness length, albedo, thermal character) within a rural surface environment and varying the appropriate lower boundary condition parameters.

2.0 Early Results

We employ a set of sensitivity experiments in two-dimensions (x-z grid at 0.5 km resolution). The Advanced Regional Prediction System (ARPS) model is applied using a "sand-box or urban slab" approach. A 30-km urban area is defined in the initial land surface parameters. In the simulations, the desert land type with sand is chosen to simulate the thermal properties closest to an urban surface. The prevailing flow is westerly and based on a summer 1996 Atlanta sounding day studied by Bornstein and Lin (2000). In the CONTROL experiment, the initial horizontal temperature anomaly profile varies linearly from 0.0° at the urban edges to 2.0° at the urban center. The roughness length increases linearly from 0.01 (edges) to 1.0 m (urban center). The vegetation fraction also decreases linearly from 0.3 (edges) to 0.1 (urban center). Each of these initial model profiles is based on the classical, idealized UHI distribution of temperature, roughness, and vegetation in an urban area.

Very preliminary results from the study suggest that roughness exerts a control on the amount and timing of urban-induced precipitation falls directly over the city. In an experiment with no variation (NOROUGH-West) in roughness across the urban area (e.g. constant roughness length of 0.01 m), rainfall was generated 20-30 km downwind of the urban center (Fig. 1). However, when the variation in temperature (NOUHI) was removed (e.g. constant 2° horizontal profile), the precipitation is found over the city. In NOUHI, the variation in roughness is the primary forcing and results indicate enhanced low-level convergence prior to convective development over the city. In experiments (not shown) INCREASED (REDUCED) the roughness at the center is increased to 2.0 m (decreased to 0.5 m). In each of these experiments the distribution and magnitude of the rainrates did not significantly differ from the CONTROL. These preliminary results, consistent with other studies, suggest that roughness length promotes increased forcing through focusing low-level convergence, primarily over the city. Results also show a tendency for experiments with increased roughness length to initiate convection 10-25 minutes earlier than the CONTROL experiment.

In NOROUGH-West, roughness was not a factor so that only the UHI thermal perturbation was generating the forcing that ultimately led to precipitation. Examining fig. 1, it is apparent that the primary precipitation region is downwind in NOROUGH-West. After examining perturbation vertical velocity fields from the model run, it is theorized that small mesoscale circulations form at the edges and center of the urban area due to gradients in the surface flux. In NOROUGH-West, the prevailing flow at all levels is westerly. Under westerly flow, an enhanced convergence zone is created between the prevailing wind flow at low- to mid-levels and the eastern-most mesoscale circulation (see fig. 2). In NOROUGH-EAST, the roughness variation is removed and the prevailing flow is reversed to easterly. As theorized, the precipitation regime shifted to the downwind region *west* of the "city".

A set of experiments (not shown due to space restrictions) has also been conducted in which the size of the urban area varies from 20 km to 40 km using the same initial profiles as the CONTROL experiment. Early results suggests that smaller cities tend to produce a maximum in rainfall downwind of the city while larger cities produce a maximum in rainfall over and slightly downwind of the center of the city. This finding is consistent with some of Thielen et al. 's (2001) work. Another set of experiments varies the initial magnitude of the surface perturbation from 2.0 ° to 8.0°. In these experiments, the distribution and location of precipitation does not vary significantly, but a downwind region of precipitation is significantly greater for the 8° UHI than the smaller magnitude UHI. This outcome is likely due to larger boundary layer destabilization resulting in more vigorous meso-circulations (Fig. 2).

3.0 Concluding Remarks

The paper introduces *very* preliminary results from the modeling component of a remote sensing-modeling effort on urban induced rainfall. Such research has implications for weather forecasting, urban planning, water resource management, and understanding human impact on the environment and climate.

4.0 References Available Upon Request

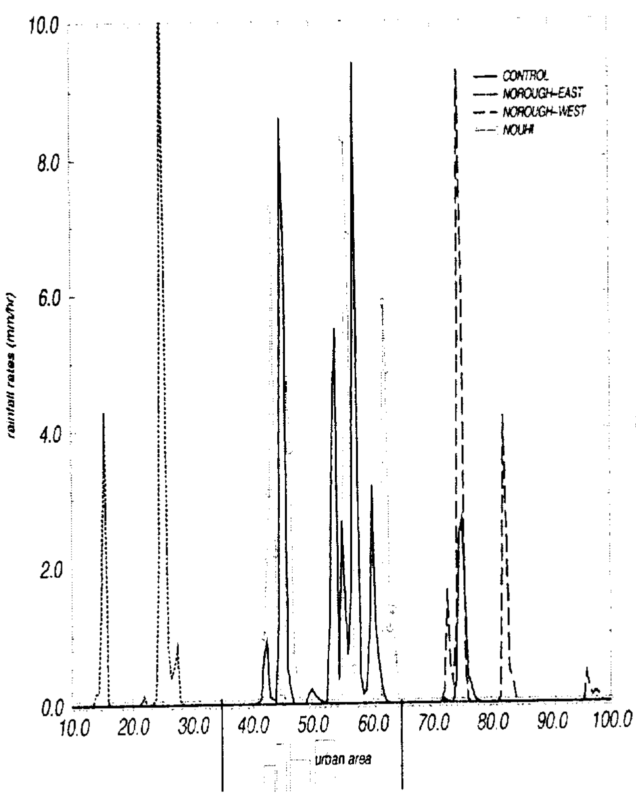

Figure 1-Rainfall Rates as a function of time.

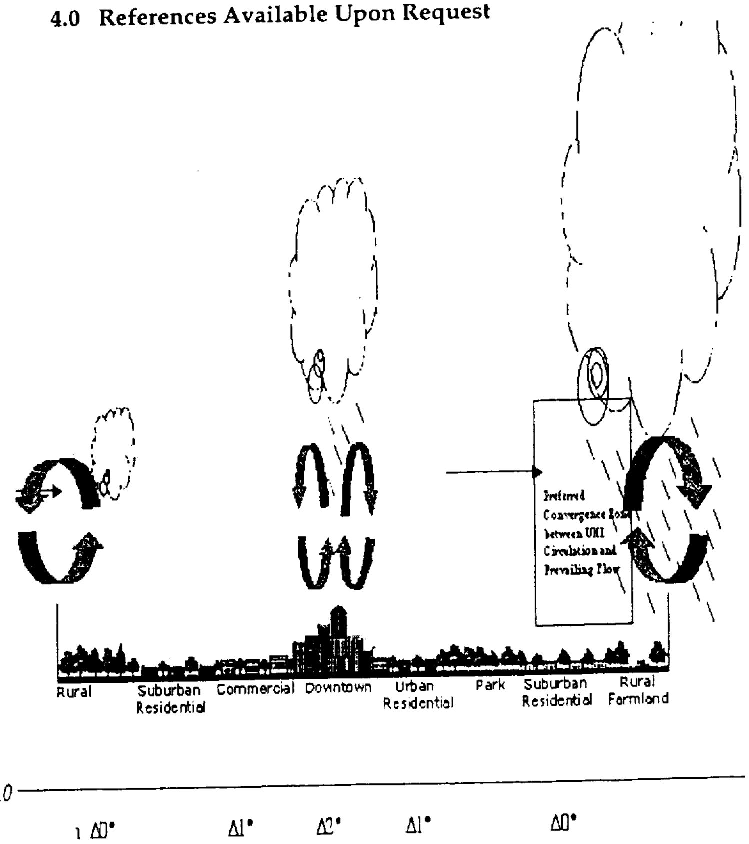

Figure 2-Preferred UHI convergence regions.

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